ALL ABOUT ATTENUATORS

RON TIPTON

Here's some information on how attenuators work, how they're used, and a small sampling of circuits you can use the next time you need one.

An attenuator is defined as "a device used to reduce the power (or voltage) level of a signal while introducing little or no distortion." They come in all shapes and sizes and can be arbitrarily placed in two general groups: active and passive, and the passive grouping can be further divided down into fixed and variable subgroups. As the name implies, the passive attenuators use only resistors to reduce the signal level, while the active devices use transistors or ICs to perform a resistance function. In this article, we are going to look into the various types of attenuators and attenuator circuits, show you how to use them, and show you how you can build your own.

Passive Fixed Attenuators. This type of attenuator is readily available as an off-the shelf commercial product and is most often packaged as coaxial or plug-in modules. The coaxial models are usually built with SMA, N, or BNC connectors, as well as with special connectors such as the General Radio type "GR874," and have a usefully flat response from DC to 6 GHz (6000 MHz). Typically, plug-in units have 0.030-inch diameter pins arranged on a tenth-inch grid to allow them to plug into sockets or socket pins on a printed circuit board. Plug-in units are usually rated for a flat response from DC to 1500 MHz.

Inside, a passive fixed attenuator is made up of resistors connected in a "tee" or "pi" configuration as shown in Fig. 1. Also shown in that figure are the values of resistors needed for various levels of attenuation. Those values assume a 50-ohm line impedance, but values can be calculated for 75- or 93-ohm lines if needed.

Coaxial models could be built using ordinary ¼- or ½-watt metal-film resistors, but then their high-frequency response would be limited to a few hundred megahertz at best. The 6-GHz (and higher) range is achieved using special coaxial resistors in which the thin resistive film is deposited on ceramic forms that physically match the size of the outer conductive shell.

Both coaxial and modular (plug-in) attenuators are used to reduce power levels, set mixer input levels, balance phase-detector inputs, and so forth. Fixed models are generally less expensive and perhaps more stable than a variable unit would be in those applications.

One final note before we move on. Both the tee and pi networks work equally well. If building your own attenuator, the choice of which to use is largely determined by available resistor values.

Passive Variable Attenuators. This category is much larger than the "fixed" group, because it contains switched-tee and -pi units, continuously-variable attenuators, and voltage dividers.

It is easy to build a switched-tee attenuator. All you need are some 1% metal-film resistors, DPDT toggle switches, input and output connectors, and a suitable case. The circuit diagram in Fig. 2 shows a 50-ohm attenuator that can be set from zero to 61 dB in 1-dB steps. A tee design was used because it proved to be a better fit to standard resistor values. The author's completed unit, which is shown at the beginning of this article, uses male BNC connectors and a cast aluminum case, such as those stocked by Mouser Electronics, Digi-Key Corporation and others (size isn't especially critical for this application). Some commercial attenuators use Teflon-body toggle switches to help extend the frequency range, but ordinary, off-the-shelf switches are usable to 50 MHz or higher if care is taken during construction.

This unit is used by the author for setting the output level of oscillators and function generators with inadequate internal attenuators, or none. It's also useful for checking the automatic gain control (AGC) range in a new receiver using a real off-the-air signal: just connect the attenuator between the receiver and antenna, tune in a signal, and increase the attenuation until the signal is lost.

Of course, any potentiometer, or "pot," is a continuously-variable attenuator. We use them in dimmer circuits for setting room illumination and controlling the sound level from all kinds of entertainment equipment, as well as in a myriad of other

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applications. But sometimes a simple pot won't do. Figure 3 shows a constant-impedance continuously-variable attenuator used to set a function generator's output level. This particular circuit was used in the Hewlett-Packard model 3300A function generator, but it is typical of the breed. It provides a fairly constant 600-ohm output impedance that is independent of the voltage setting. The spec sheet says it has a 40-dB range; actually it's about 45 dB. This is a useful circuit to keep in your bag of tricks, although finding the ganged pots might be a challenge.

Voltage Dividers. Since all attenuators are also voltage dividers, you might wonder why they are treated as a separate group. Though the author has not seen it stated this way, the difference in general is that attenuators are matched to the impedance of their source and load, while voltage dividers aren't. Voltage dividers usually have a fairly high input impedance so they don't load the driving source. And they need a low enough output impedance so that their load does not appreciably change the output voltage.

Figure 4 shows a simple switched divider that the author built to increase the output voltage range of a function generator. It has a 10,000-ohm input resistance, which can be easily driven by the generator's 50- or 600-ohm output. A one-megohm or higher load, such as a voltmeter, changes the output voltage by no more than 1% at any switch setting. If built into a small cast aluminum case, this useful workbench accessory can be used wherever it is needed. The resistor values are easily scaled if you need either a higher or lower input resistance.

Precision voltage dividers are known as Kelvin-Varley dividers and often have large coin-silver switch contacts (for low resistance) as shown in Fig. 5. The circuit diagram for this unit (see Fig. 6.) shows a four-decade divider, though it could be extended to five, six, or even seven decades as needed. So, how does this divider work?

There are 11 equal-value resistors in the first or input decade. But two of those series resistors are always in parallel with the second decade. The second decade has a total series resistance equal to the paralleled pair in the first decade. Thus, the first decade looks like a simple 10-resistor divider.

ATTENUATION (dB)	TEE R1 (Ω)	TEE R2(Ω)	PI R1 (Ω)	PI R2 (Ω)
1	2.9	433.3	870.0	5.8
2	5.7	215.2	436.0	11.6
3	8.5	141.9	292.0	17.6
4	11.3	104.8	221.0	23.8
5	14.0	82.2	178.6	30.4
6	16.6	66.9	150.5	37.3
7	19.0	55.8	130.7	44.8
8	21.5	47.3	116.0	52.8
9	23.8	40.6	105.0	61.6
10	26.0	35.0	96.2	71.2
11	28.0	30.6	89.2	81.6
12	30.0	26.8	83.5	93.2
13	31.7	23.5	78.8	106.0
14	33.3	20.8	74.9	120.3
15	35.0	18.4	71.6	136.1
16	36.3	16.2	68.8	153.8
17	37.6	14.4	66.4	173.4
18	38.8	12.8	64.4	195.4
19	40.0	11.4	62.6	220.0
20	41.0	10.0	61.0	247.5
21	41.8	9.0	59.7	278.2
22	42.6	8.0	58.6	312.7
23	43.4	7.1	57.6	351.9
24	44.0	6.3	56.7	394.6
25	44.7	5.6	56.0	443.1
30	47.0	3.2	53.2	789.7
35	48.2	1.8	51.8	1405.4
40	49.0	1.0	51.0	2500.0
45	49.4	0.56	50.5	4446.0
50	49.7	0.32	50.3	7905.6
55	49.8	0.18	50.2	14058.0
60	49.9	0.10	50.1	25000.0

Fig. 1. To build your own passive attenuators, a simple tee or pi network can be used. The table of values in this figure assumes a line impedance of 50 ohms.

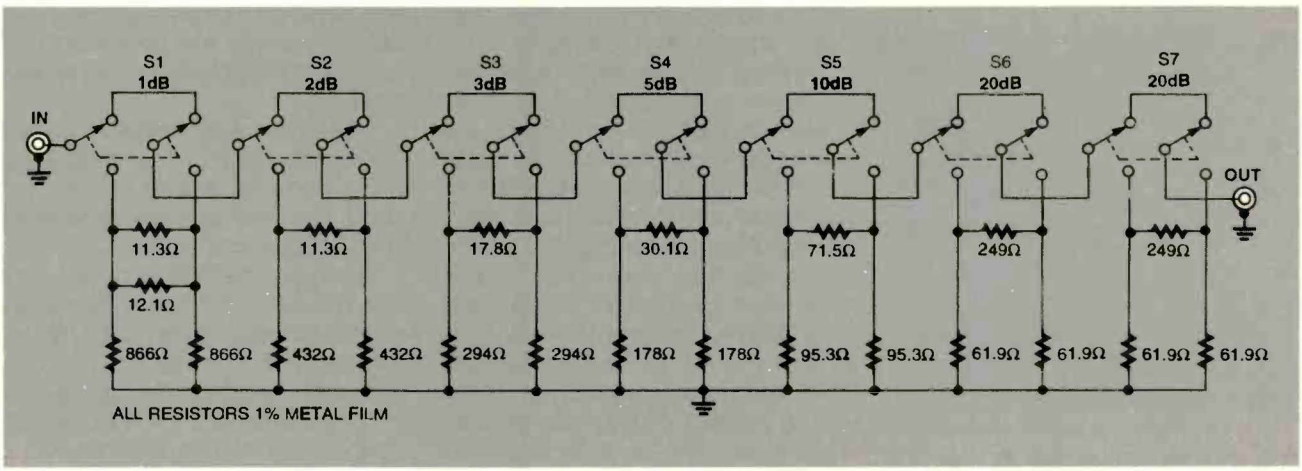

Fig. 2. Here's a 50-ohm attenuator that can be set from zero to 61 dB in 1-dB steps. A tee design was used because it proved to be a better fit to standard resistor values.

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Continuing on, we see that this scheme is repeated: The third decade is always in parallel with two series resistors in the second decade, and so on. In short, we get a constant 5-to-1 resistance ratio between successive decades, which means that the resistance values can get rather small as we add decades. That becomes the practical limit on how many decades we can add. A seven-decade divider with a 100,000-ohm input resistance needs 0.64-ohm resistors in the last decade. The last decade is always a ten-step divider, or continuously variable pot, to enable a "unity" output. If that were not done, the maximum output would be 0.9999 (for four decades), which wouldn't quite do the job.

Kelvin-Varley dividers are usually built with highly accurate and stable resistors so as to have excellent linearity. Older models from companies such as General Radio, Electro Scientific Industries (ESI), John Fluke, and IET Labs often work as well as they did when new, even if that was 30 or 40 years ago!

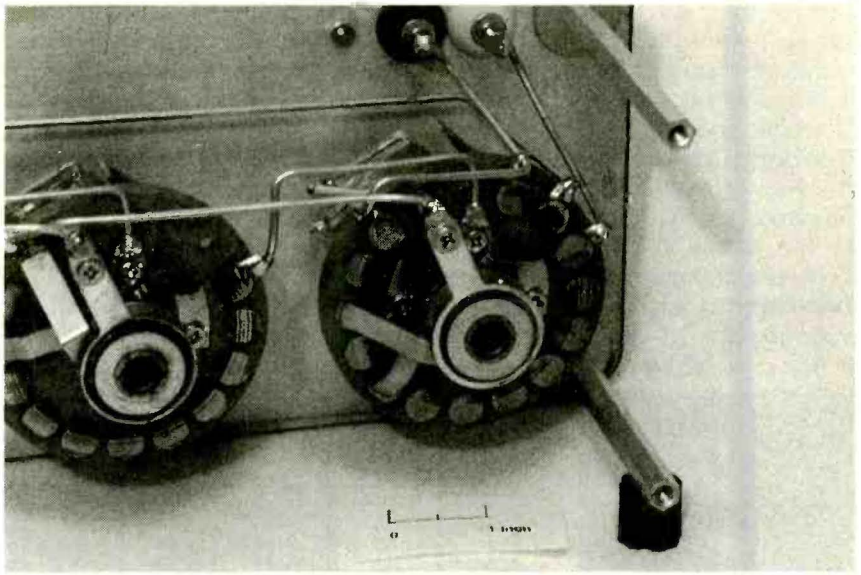

Fig. 5. This General Radio Kelvin-Varley voltage divider features low resistance coin-silver switch contacts and precision wire wound resistors.

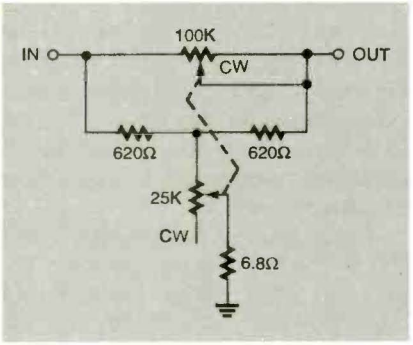

Fig. 3. Originally used in the HP-3000A function generator, this continuously variable attenuator provides a fairly constant 600-ohm output impedance that is independent of the voltage setting. Note that the potentiometers are ganged on a single shaft.

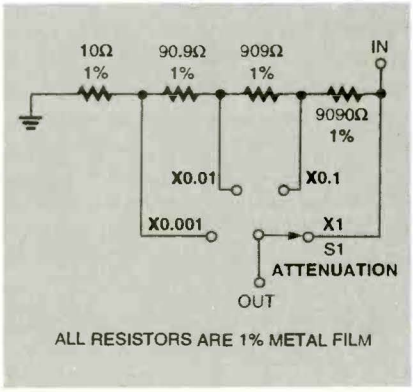

Fig. 4. This simple switched voltage divider was built by the author to increase the output voltage range of a function generator. It has a 10,000-ohm input resistance.

Active Attenuators. Active attenuators are frequently designed so that the level of attenuation can be digitally controlled, say by a computer or microprocessor, but that is not always the case. For example, the Motorola Semiconductor MC3340P is controlled by a DC voltage or an external variable resistor (which controls a DC current). With a frequency response that's flat to about a megahertz and an attenuation range of more than 80 dB, that is quite a versatile component. The total harmonic distortion in the output signal rises to over 3% at attenuations of more than 40 dB. Whether that is acceptable or not will depend on your application.

Analog Devices calls its AD8402 a "digital potentiometer," because it uses an 8-bit input to control the wiper setting of a three-terminal "pot." That is, the wiper can be set to 256 different positions, with a digital input of 128 setting the pot to mid-scale. That 14-pin DIP IC is programmed through a 3-wire serial interface. A microcontroller such as one of the PIC models from Microchip Technology Inc. can read the on/off settings of a group of eight toggle switches or a thumbwheel switch and do the programming.

The author has used the AD8402 to build tunable active filters and in the process has learned that it's not quite an ideal resistor. The device still has some resistance, about 50 ohms in the 10,000 ohm unit, even when the digital input is all zeros.

Another limitation is that the AD8402 prefers that its associated circuit operate using the same supply voltage as it does; that is, ground and +5 volts. If there are op-amps in your circuit, they also need to operate between ground and +5 volts, which means you'll need a +2.5-volt virtual ground to bias the op-amps to the power supply midpoint. Also the microcontroller clock will introduce some noise into your analog signal—if you let it: The AD8402 contains latches that store the last programmed data; that means you can minimize the clock-noise problem by putting the microcontroller to sleep except when actually programming.

Don't be discouraged by that litany of problems; the AD8402 is a very useful component. You just need to be aware of its limitations and design around them.

Another alternative here is the LM1972 from National Semiconductor. It is billed as an audio attenuator, and the author has successfully used it in several industrial-control applications. Like the AD8402, its attenuation is programmed over a 3-wire serial interface. But unlike the AD8402, its attenuation changes

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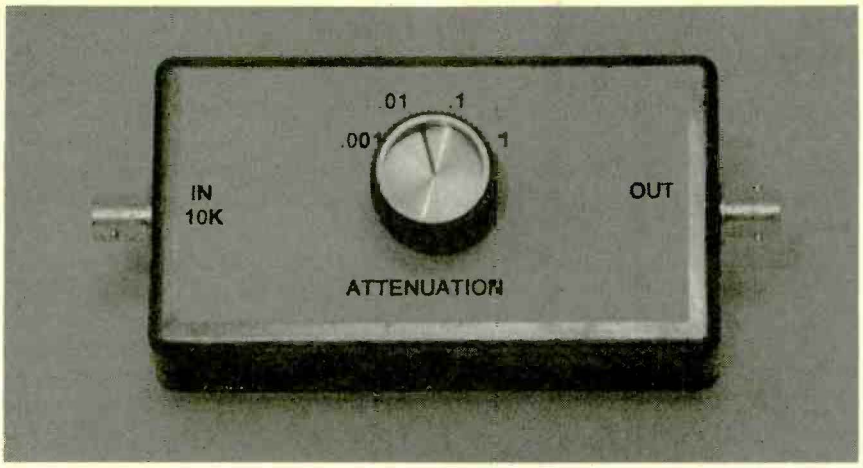


Here's the author's version of the circuit shown in Fig. 4.

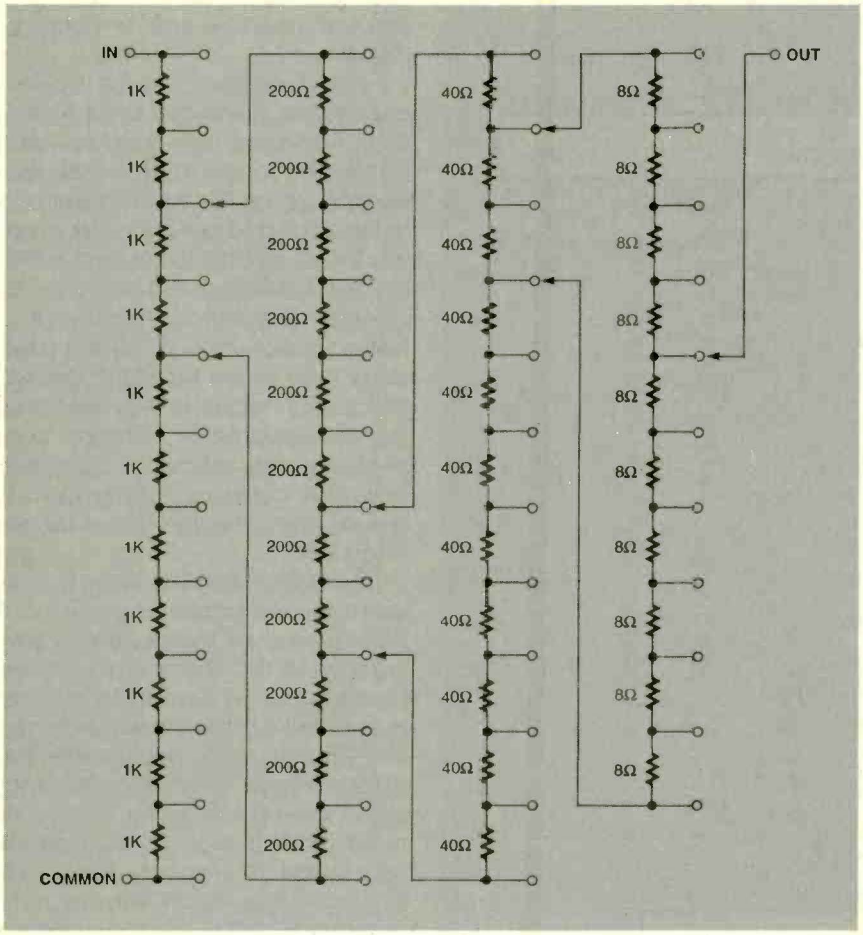
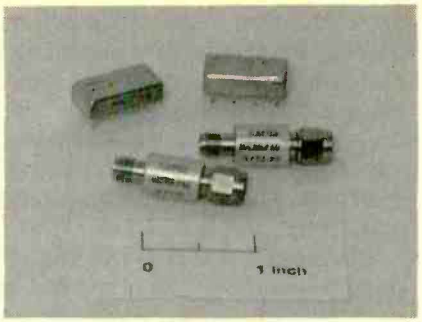


Fig. 6. The circuit diagram for the divider shown in Fig. 5 reveals that it is a four-decade device with a 5-to-1 resistance ratio between decades.



A pair of coaxial units with SMA connectors made by Narda Corporation (now Loral Microwave Narda), and a pair of plug-ins manufactured by Mini-Circuits.

RESOURCES

Analog Devices
PO Box 9106
Norwood, MA 02062-9106
Tel: 800-262-5643

Digi-Key Corporation
PO Box 677
Thief River Falls, MN 56701-0677
Tel: 800-344-4539

Loral Microwave Narda
435 Moreland Road
Hauppauge, NY 11788
Tel: 516-231-1700

Microchip Technology Inc.
2355 W. Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 602-786-7200

Mini-Circuits
PO Box 350166
Brooklyn, NY 11235-0003
Tel: 800-654-7949

Motorola Semiconductor Products
2100 E. Elliot
Tempe, AZ 85284
Tel: 602-244-6900

Mouser Electronics
958 N. Main Street
Mansfield, TX 76063-4827
Tel: 800-346-6873

National Semiconductor
2900 Semiconductor Dr.
Santa Clara, CA 95052-8090
Tel: 800-272-9959

Scott Edwards Electronics
PO Box 160
Sierra Vista, AZ 85636-0160
Tel: 520-459-4802

from zero to 78 dB in 0.5-dB steps up to 48 dB and then in 1-dB steps on up to the maximum. The frequency response is down 3dB at 100 kHz, and the total harmonic distortion (THD) plus noise is specified at 0.003% maximum. (National has targeted music-system applications with this device so they wanted it to be really quiet!)

Figure 7 is a circuit diagram of a variable attenuator you can build around an LM1972. Let's take a look at how it works.

The circuit makes use of a 1-of-12 keypad, which the author had on hand, to enter the desired attenuation. The line from each key connects to one of twelve input pins on a PIC16C73 microcontroller (as indicated by the dots on the lines from the specific pins on the IC). Each of these inputs is normally pulled up to +5 volts through a 4700-ohm resistor

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(R1-R12). When a key is pressed, the connected PIC input is pulled low and the firmware stores the key's value. In this design, the # key is used for "enter." When that key is pressed, the entered attenuation is programmed into the LM1972 over the clock, load, and data lines.

The LM1972 has an input impedance of about 40,000 ohms, but its output impedance is also high so an output buffer is needed. Most any JFET-input op-amp will work. The author selected an LF412 because it has a full power output bandwidth greater than 100 kHz and a low DC offset. You'll notice that this design is DC coupled, so it's ideal to use with a function generator that tunes to very low frequencies. But if your input signal has much DC on it, you will need to use a coupling capacitor.

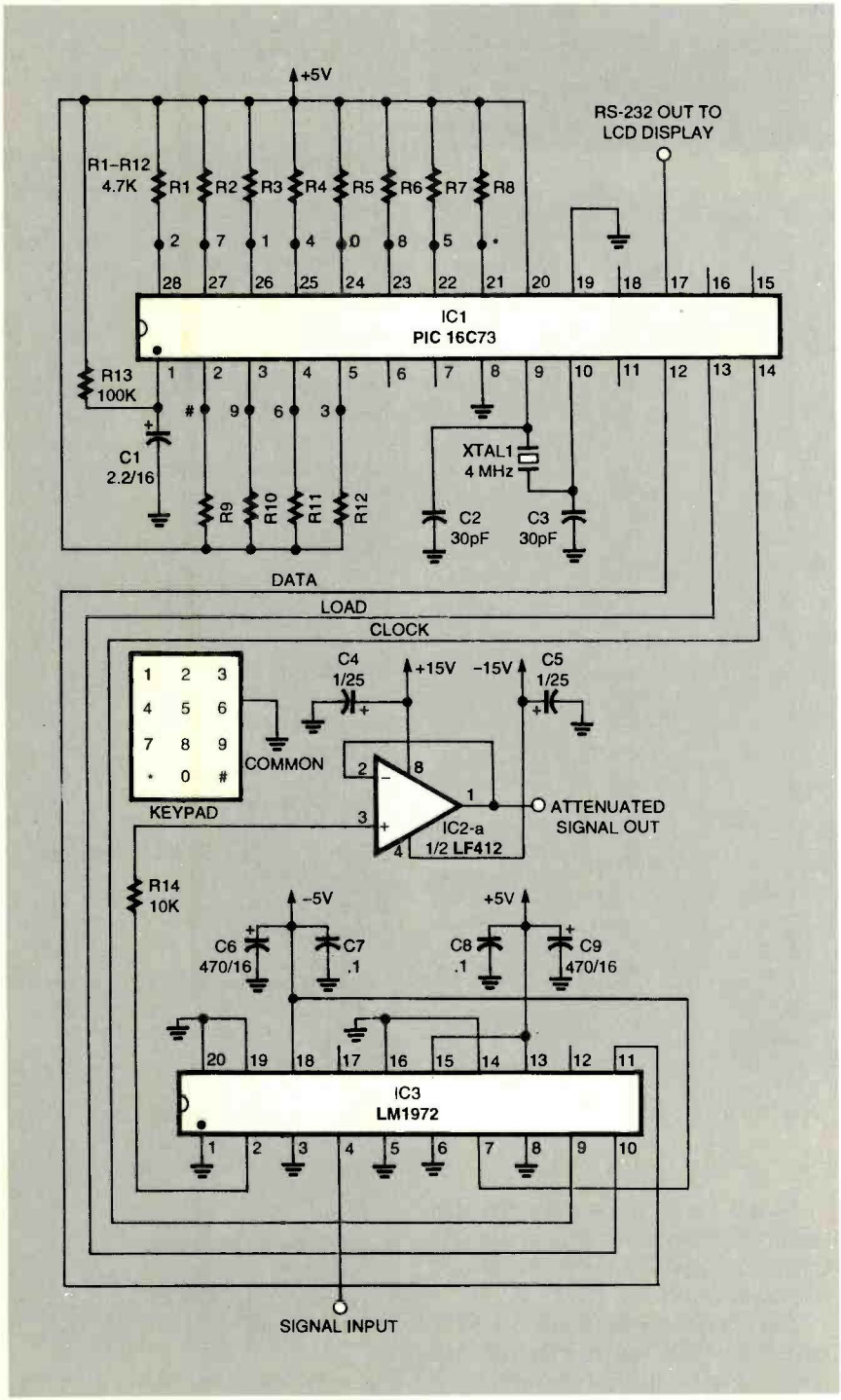

Fig. 7. Here's a digitally-controlled variable attenuator built around National's LM1972. It is ideal for audio/music applications. The program for the microcontroller can be downloaded from the **Electronics Now** *ftp site (ftp.gernsback.com/pub/EN).*

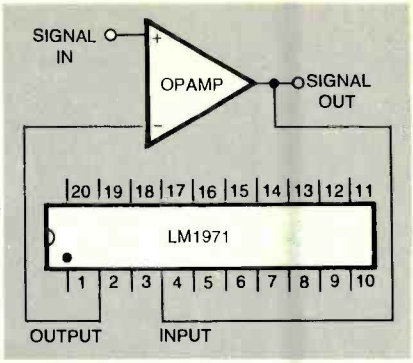

Fig. 8. This simple change lets you use the LM1972-based circuit in Fig. 7 as a variable-gain amplifier.

Lots of different display options are possible. The author used an LCD Serial Backpack from Scott Edwards Electronics to display the attenuation, though an RS-232 line driver had to be added to get it to work properly. If you decide to go that route, an "old-fashioned" LM1488 operating from the ±15-volt supplies is a better choice than a "+5-volt only" driver such as the MAX232A (Maxim Integrated Products). With the latter, the voltage-doubler switching transients are very difficult to decouple from the output signal, and that greatly limits the maximum usable attenuation.

The output signal voltage is limited to 10 volts peak-to-peak (about 3.5 volts rms) by the ±5 volts supplying the LM1972. That supply can be increased to ±7.5 volts (maximum) but ±5 volts is more convenient since the +5 volts can also power the microcontroller. The minimum output signal level is limited by microcontroller clock pickup, so it would be very useful to stop the clock. The firmware does that: After programming the LM1972 (which has latches to store the most recent data), the microcontroller goes to sleep which stops the clock. Pressing the star key (*) generates an interrupt that wakes up the PIC, which then waits for the next keypad entry.

The well commented source code (written in C) and the hex file needed to program the PIC are available on the **Electronics Now** ftp site (ftp.gernsback.com/pub/EN) in file ATTEN.ZIP. Application Note

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Union meeting, the LANL team of Tilden, Moore, and Janette Frigo presented an idea for a constellation of microsatellites, each weighing no more than half an ounce with control systems based on the simplest animal neuron "twitches." You could carry these satellites in your pocket and launch them out of the shuttle cargo bay with a slingshot.

According to Tilden, a well-known innovator in the close-knit robotics community, the control systems of these insect-sized satellites are based on simple "nervous nets" (Nv), an instinct-like neural net in which a single electronic neuron is sufficient to produce a control pulse, or twitch, in a robotic creature lacking an advanced processor or computer command. Nv technology is based on the notion that a brain is of no use without a spinal cord. Indeed, most life on earth survives just fine without any brain at all.

Their "satbot," resembling a carefully folded sheet of construction paper, has three solar cells, a long-range antenna dish the size of a button, a short-range antenna probe no longer than a toothpick, a local sensor array, and three alignment coils. It weighs 10 grams and would fit in your hand.

That weight, say the researchers, not only reduces cost, but improves accuracy and response of the satellites for ranging and orientation purposes. The basic idea is to launch these satbots by the hundreds, huge stacks of them shearing themselves in orbit as a sweeping array of sensory "pixels," giving a whole new spectrum on the potentials of data measurement.

The whole idea is founded on the fact that space exploration is expensive and risky. However, Tilden says, satellites can be built cheap, rugged, self-programming, and radiation hardened. Those microsats may be the first step toward a whole range of long-term, low-cost space missions that would otherwise be prohibitively expensive.

Big Missions for Small Craft. Beyond mapping the Van Allen Belt, other, potential applications include measuring the solar wind and more precise earth imaging. And that's just the beginning.

"We've done work on everything from lunar dust clearers, lunar miners and sorters, self-organizing heat-resistant tiles, broad-field pixelsats that can image asteroids or vast areas of space, to low earth orbit debris removers and single-mechanism interstellar explorers," says Tilden. "And there's not a computer in any of them. Most of them aren't even as complex as a transistor radio. Maybe it's a paradigm shifting without a clutch, but at least our devices work.

"The real goal eventually is to set up a whole organized branch of alternate robotic sciences powerful enough to think about colonization, and not just interstellar exploration," Tilden says. "The benefits will come from cheap access to space for people other than the big boys, and in innovative techniques that don't require NASA dependence. Find a way to sell a Sharper Image satellite for a thousand dollars with your choice of small payload, accessible and/or controllable through the Internet, and you'll see a revolution in amateur astronomy equal to the first ground-glass lens."

Tilden's nervous nets work like the neurons in animal nervous systems, which put out spiked pulses that hold useful information in the timing between the pulses. In computer terms, he says, the information needed to do work lives in the firing rate, not in a coded voltage level.

The Los Alamos satellite model shown in the beginning of this article is a microsatellite controller whose primary mission is to orient itself in earth's magnetic field. Using only a few transistors, those space 'bots seek the brightest available source—the sun—and orient themselves precisely toward it.

Acting like a delay line, the researchers say, electronic pulses from photodetectors travel first to one neuron and then the next. By adjusting the timing relationship between the pulses, the control system seeks the light and uses the reaction of the controller's magnetic field against earth's magnetic field for the torque needed to orient the satellite. With six neurons on three axes, the controller can move or examine different points in three-dimensional space.

Moore says hundreds of microsatellites in orbit could relay simple streams of data to a communications mothership, which could integrate the data and pass it to ground stations. Measuring earth's magnetosphere is one potential mission. By locating a swarm of microsatellites on the sunward side of the magnetopause, scientists can take real-time measurements of the energy transferred to earth's magnetic field by the turbulent solar wind. "We've never been able to do real-time monitoring of the position of the magnetopause as the solar wind pushes it around," says Moore. "With hundreds of these microsatellites we should be able to do that." Ω

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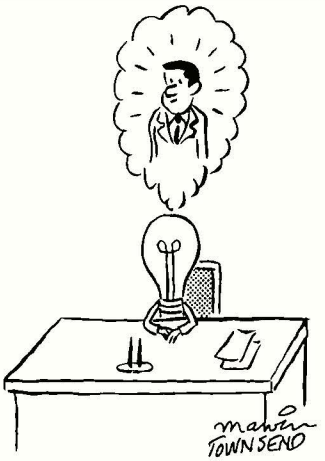
AN529, available from Microchip Technology Inc., describes a 4 3 4 sampled keypad and LED driver that could also be used to set and display the attenuation.

A simple change, shown in Figure 8, lets you use the LM1972 as a variable-gain amplifier. Since the op-amp shown in the figure has a low output impedance, a separate output buffer is usually not needed.

The author is available to answer (or try to answer) questions on any of the devices in this article. I'm usually difficult to reach by phone so please write, fax, or e-mail Ron Tipton, 5260 Cochise Trail, Las Cruces, NM 88012; Fax: 505-382-8810; e-mail: RTipton@zianet.com. Ω



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